Large amplitude variations recorded by an on-fault seismological station during the L'Aquila earthquakes: evidence for a complex fault-induced site effect

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! Motivation: One station, FAGN, installed on a segment of the fault system that generated the April 2009 earthquakes, shows anomalously larger ground motions compared the nearby stations.

A

- This study focuses on a large amplification observed at the on-fault station **FAGN** and the modeling of the fault-guided propagation effect.
- **FAGN** is located on the S. Demetrio fault (Vezzani and Ghisetti, 1998) and the presence of the fault zone beneath the station could play a role on the observed amplifications (Davis et al., 2000; Cultrera et al., 2003; Karabulut and Bouchon, 2007).
- The difference in amplitude, compared to nearby stations, is extremely large for some particular events and neigligible for others of the same seismic sequence.

B

Map of the study area

We have selected 306 foreshocks and aftershocks well recorded by broad-band stations **FAGN**, **AQU** and **FIAM**.
Magnitudes are in the interval 1.8 ≤ ML ≤ 4.1 (epicenters and ML are from ISIDE data-base, available on line http://iside.rm.ingv.it).
AQU and **FAGN** are aligned NW-SE, approximately, paralllel to the strike of the causative fault system wheras **FIAM** is aligned in an approximately orthogonal direction. Geological conditions of **FIAM** are similar to ones of **FAGN**: both are on slope debris, limestone outcrops tens of meters away from the receivers; **AQU** is installed on the "Megabrecce" unit.

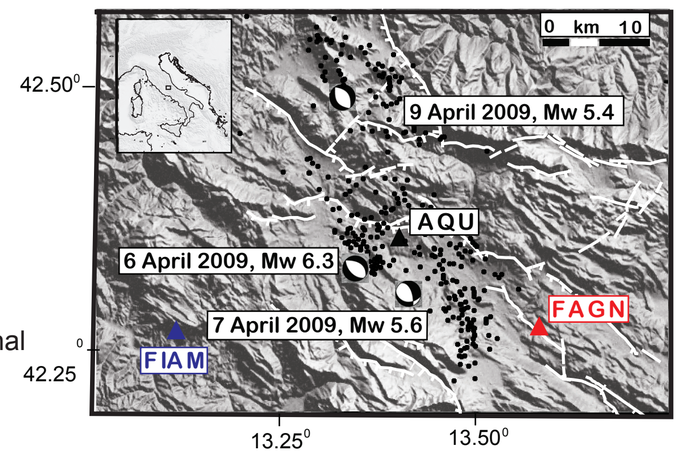


Fig. 1 **Triangles:** INGV permanent seismological stations. **Beach balls:** Major shocks epicenters (Hermann et al., 2010) . **Black dots:** foreshock and aftershock epicenters.

C

Waveforms

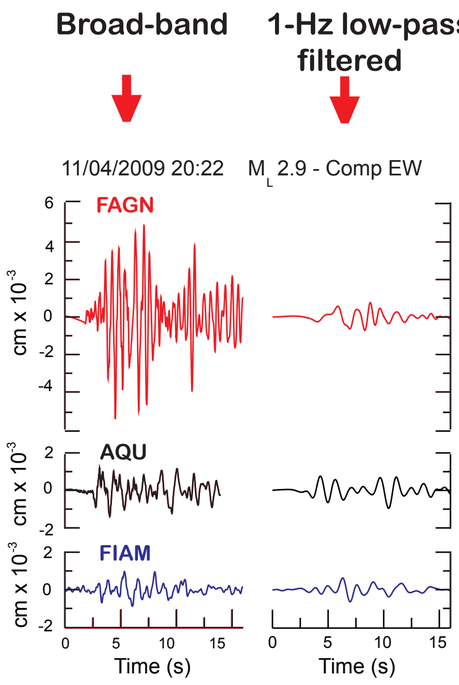


Fig. 2 One example of broad-band and low-pass (f < 1Hz) filtered displacement waveforms in the left and right-hand, respectively. The seismograms are scaled to a reference distance of 15 km.

Spectra

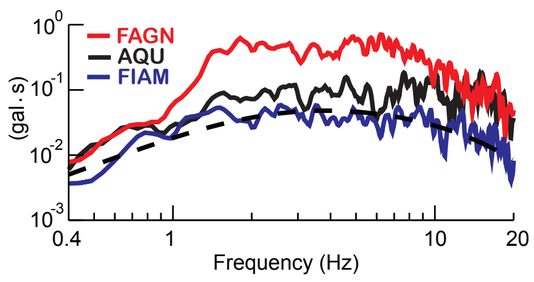


Fig. 3 Theoretical dashed curve represents the Brune (1970) model spectrum for a stress drop of 0.7 MPa (Calderoni et al., 2009). Acceleration spectra of the stations are scaled to a reference distance of 15 km.

Spectral ratios FAGN/AQU and FIAM/AQU

Average and standard deviation over 306 earthquakes

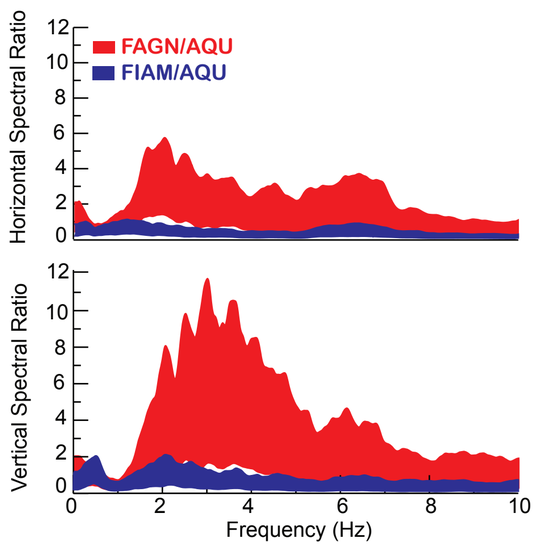


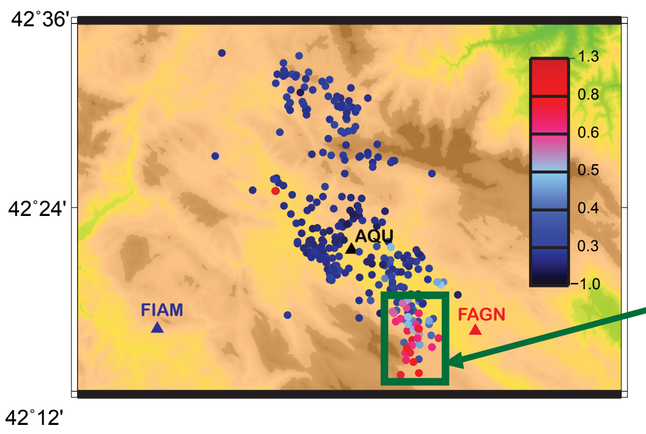
Fig. 4 Intervals of ±1 standard deviations around geometric mean of spectral ratios **FAGN/AQU** and **FIAM/AQU** for horizontal and vertical motions, averaged over the selected event ensemble.

D

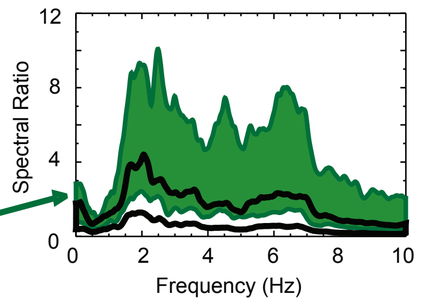
What is the origin of the large variability of FAGN?

Dependence of amplification on location of the causative earthquakes.

(a) Amplification in terms of spectral ratios **FAGN/AQU** (1<f<8 Hz, AMPi)



(c) Spectral ratios of the cluster events (green rettangle)



(b) Difference in local magnitudes

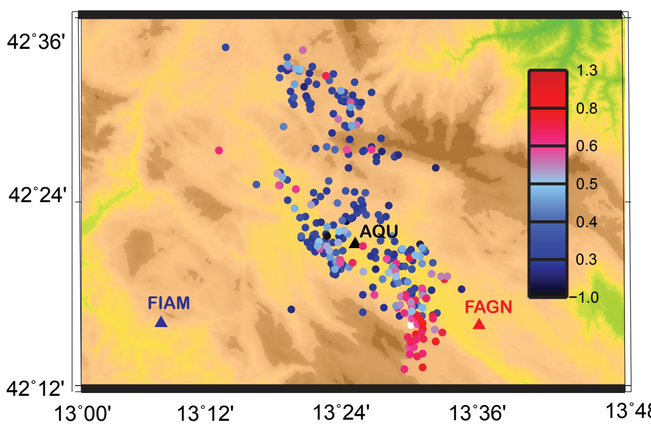


Fig. 5 The colour scale of the epicentre symbols is proportional to the logarithm of the amplification of individual events, estimated through (a) the **FAGN/AQU** spectral ratio, and (b) the difference in local magnitude ML between **FAGN** and the average local magnitude of the seismic bulletin. In (c) the green coloured band shows the ±1 standard deviation intervals around the geometric mean of 70 events with the strongest effects (those inside the green rectangle). The two black curves are ±1 standard deviations of the geometric mean of events outside the green rectangle.

Modelling propagation in the fault zone

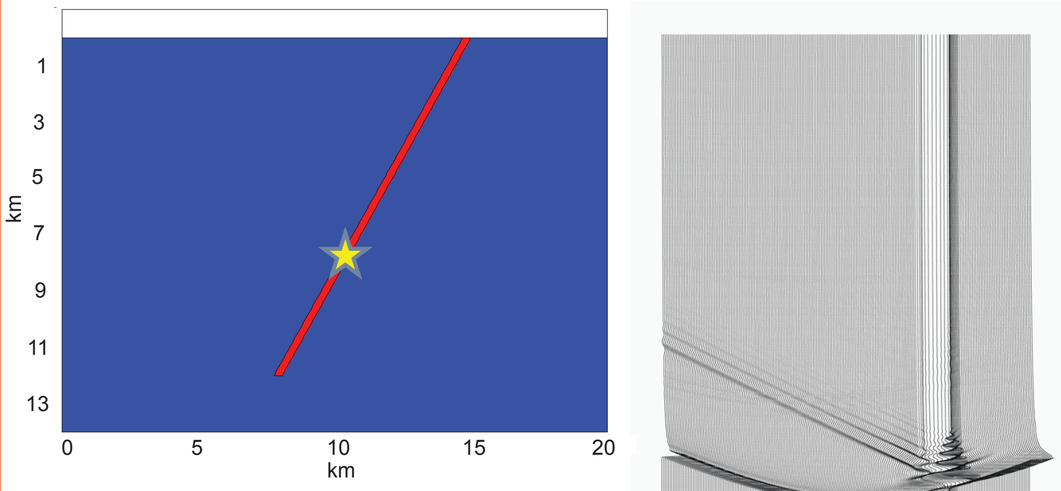


Fig. 6 An SH line source propagates in a fault zone: large-amplitude trapped waves are well evident at the surface within the fault zone, characterized by velocity reductions of 30-40%, (courtesy of Stefania Pucillo).

The target spectrum

Dep (km)	ΔVs	H (m)	Q
4	40%	80	10
5	35%	80	10
6	31%	280	20
7	28%	280	20
8	25%	280	20

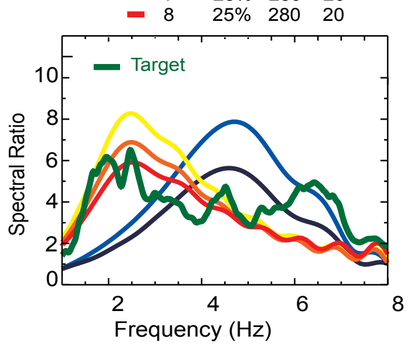


Fig. 7 Best fit models for different propagation length L in the fault zone.

What is the best model?

The model solution is not unique and there are strong trade-offs between the model parameters:
- L, length of propagation in the fault;
- ΔVs, S-wave reduction in the damage fault zone;
- H, width of the fault zone;
- Q, quality factor in the fault zone.

Using the analytical solutions by Ben-Zion and Aki (1990) we applied a grid search on H and Q after constraining L and ΔVs on the base of the trapped wave delay versus distance. The target spectrum was computed using the spectral ratios of events falling in the green rectangle of Fig.5 a (N=70).
To give greater significance to events with a good coupling with the fault, we applied AMPi as a weight for each spectral ratio $SR(f)_i$ used in the average operation:

$$TS(f) = \frac{\sum_{i=1}^{N} AMP_i \cdot SR(f)_i}{\sum_{i=1}^{N} AMP_i}$$

Conclusions

- Ground motion amplification at **FAGN** varies significantly event by event depending on source-receiver paths, the largest effects occuring when seismic waves travel in the fault zone.
- This variation is as large as a factor 10, this is confirmed both by spectral ratio estimates and local magnitude variations.
- The amplifying structure results in an about 300 m wide fault zone, with S-wave reduction of 25-30% and Q of 20.

References
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